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DESIGN AND TESTING OF A ONE-METER MEMBRANE MIRROR WITH ACTIVE BOUNDARY CONTROL (Conference Proceedings)

James D. Moore, Brian G. Patrick, Surya Chodimella (SRS Technologies)
Dan K. Marker, Brett deBlonk (AFRL)

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AIR FORCE RESEARCH LABORATORY
Directed Energy Directorate
3550 Aberdeen Ave SE
AIR FORCE MATERIEL COMMAND
KIRTLAND AIR FORCE BASE, NM 87117-5776

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James D. Moore, Brian G. Patrick, Surya Chodimella
Dan K. Marker*, Brett deBlonk*

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SRS Technologies
500 Discovery Drive
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*Air Force Research Laboratory
3550 Aberdeen Avenue SE
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14. ABSTRACT
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15. SUBJECT TERMS
Membrane mirror, boundary control, lenticular, lightweight

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Design and testing of a one-meter membrane mirror with active boundary control

James D. Moore, Brian G. Patrick, Surya Chodimella
SRS Technologies, Huntsville AL, USA 35806

Dan Marker, Dr. Brett deBlonk
Air Force Research Lab, Kirtland AFB

ABSTRACT

The use of thin-film membranes is of considerable interest for lightweight mirror applications. The low areal density makes them ideal for large aperture imaging applications. One type of setup looked into in the past has been the lenticular design, which consists of a clear canopy attached to a reflective film that uses positive pressure to set the curvature of the mirror. One drawback to this concept has been the fact that too much error was introduced during the pass through the canopy due to material inhomogeneities and poor optical properties. This is no longer an issue thanks to developments over the past several years in the field of optical-quality polymer development. Thin-films (< 24 microns) can now be routinely made with surface roughness, thickness variation, and very good transmission properties well within specification for many visible and IR applications. The next step in this developmental process has been maintaining a prescribed figure in the mirror. This paper summarizes the current efforts in fabricating and testing a 1-meter class lenticular membrane mirror system utilizing active boundary control and stress-coating applications to form a usable aperture for visible imaging applications.

Keywords: Membrane mirror, boundary control, lenticular, lightweight

1. INTRODUCTION

Analysis has been conducted to design a meter-class mount to support a pressure augmented membrane mirror (PAMM) system with active boundary control. Previous studies[1] have shown that active boundary control can be very effective for correcting certain types of figure errors typically seen in membrane mirrors. Of the various active boundary control configurations evaluated, the best performance was achieved by a design that used a combination of out-of-plane boundary warping and electrostatic pressure actuators located circumferentially around the outer diameter of the membrane just inside the boundary support ring. Almost 100% correction of the simulated coma and astigmatism was predicted with this configuration. This mount will utilize electrostatic pressure control (36 electrostatic force actuators located circumferentially around the outer 1 inch of the membrane outer diameter) coupled with boundary warping (36 out-of-plane normal actuators) to demonstrate the feasibility of boundary control on a membrane mirror system along with stress-coating applications to reduce the inherent spherical aberration. This paper summarizes the current progress to-date on the design and fabrication of this mirror mount.

2. MEMBRANE MOUNT DESIGN

A small-scale prototype mounting system was first designed and fabricated for initial testing of an active boundary control and for computer model correlation. This mount is a split lenticular system, allowing one canopy and many membrane mirrors that can be interchanged. The mount has a clear aperture of 0.25m with the entire mount having an outer diameter of 0.33m. This mount incorporates a series of boundary actuators that allow radial and out-of-plane control. Testing was conducted to compare to Finite Element Models (FEM) developed to determine the affect of the actuators on the membrane shape. There are a total of 36 actuators, 18 radial and 18 normal. Both sets of actuators are simple thumb screws. The normal actuators are used to control the planarity of the contact ring, which dictates the membrane boundary. The radial actuators push on the ring that the membrane is adhered to, locally adjusting the film stress around the boundary. FEMs developed to determine the affect of the actuators on the membrane shape showed that the radial and normal actuators can significantly reduce the amount of astigmatism, coma, and slightly decrease spherical aberration. **Figure 1** shows this mount with a pressurized reflective membrane. Results of this testing revealed good correlation based on the accuracy achievable with the thumb screws used for this mount, details of which are described elsewhere[2].

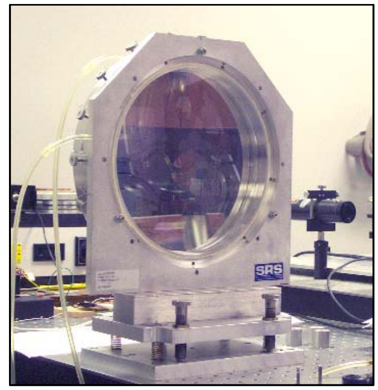


Figure 1. Lenticular on small-scale boundary control mount.

Baseline structural design requirements were established, and preliminary analyses were conducted for the initial sizing of the meter-class mirror mount. The 0.25m mirror mount design described was used as a baseline to scale up to the full size piece. The test article design is a 0.78m diameter (31-inch) clear aperture parabolic mirror set at an f/2. The mirror is formed by pressurizing a flat isotropic CP1-DE membrane mounted in a planar circular reflector ring. The magnitude of pressure required to inflate the flat membrane to an f/2 parabolic mirror depends on the amount of tensile stress in the membrane. The membrane is assumed to have an intrinsic tensile stress (pre-stress) during the curing process due to CTE mismatch between it and the substrate upon which it is cast. Tests are currently underway that include of tough flexible polymer films with CTE's matching Aluminum and other substrates. Low CTE polymers are a possibility for use later on this mirror mount in order to athermalize the complete design. However, higher membrane pre-stresses (**Table 1**) help to reduce the figure errors, primarily spherical aberration, often experienced during testing of PAMM hardware. Though the high pre-stress cannot be achieved during the curing process with a low CTE polymer, it can be accomplished by applying an increased force on the planar boundary ring that will contact the membrane.

CTE	25.2e-6 /C	43.9e-6 /C	63.5e-6 /C
Pre-stress (psi)	1886.4	4060	6314.75
Pressure (psi)	0.01484	0.02588	0.0373
Spherical aberration (microns)	220.077	137.053	101.351
RMS figure (microns) (Z_0-Z_3 terms removed)	98.0977	61.1029	45.2055
P-V (microns) (Z_0-Z_3 terms removed)	340.897	212.492	157.968

Table 1. Variation in Surface figure with membrane pre-stress.

Sizing of the planar boundary ring was conducted to achieve an out-of-plane actuator displacement of 50 microns with minimum amount of force for the normal displacement actuators. Analyses were conducted on a boundary ring with arbitrary dimensions (**Figure 2**) with two different types of support, posts and a continuous ring. A 3-D finite element model with solid elements was created in Algor for this analysis. Stress and buckling were not critical in both cases but the boundary ring with continuous support required a higher force (73 lbf) to produce the same 50 micron displacement as opposed to 6.2 lbf with support posts. Based on this analysis, it was decided to use support posts for this larger mirror mount. **Figure 3** shows the displacement plot of the ring with support posts and four actuators moved to a bias location of 50 microns each. The thickness of this reaction support structure for the out-of-plane actuators is based on a self-established stiffness requirement of 10 times relative to the boundary ring. The reaction support ring thickness is calculated to be 0.270 inches.

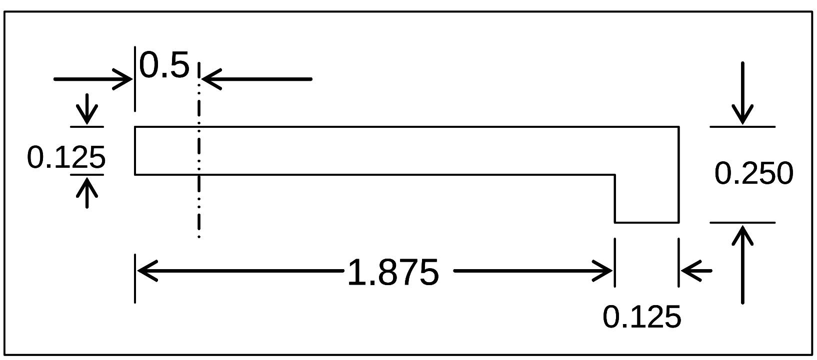


Figure 2. Cross section of planar boundary ring (All dimensions in inches).

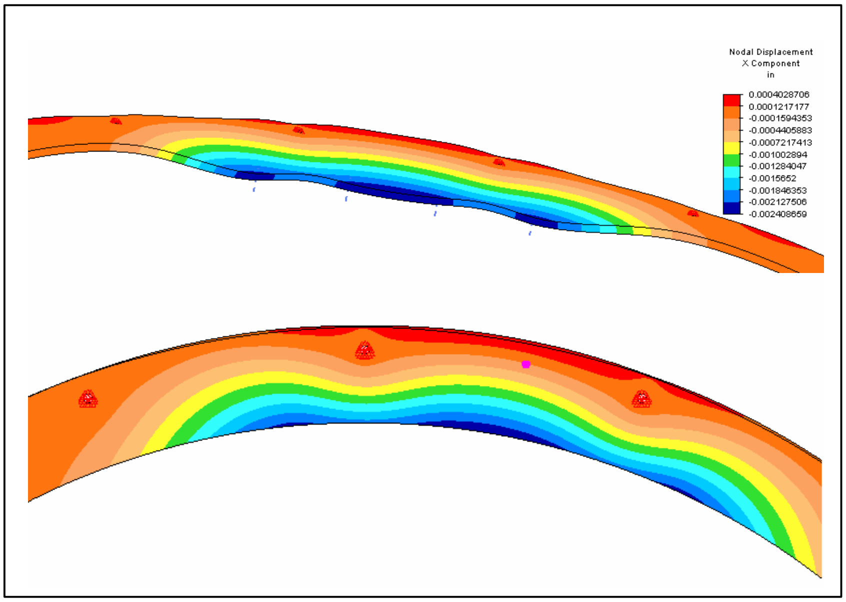


Figure 3. Deflection shape of the planar boundary ring.

Based on previous analysis[1] electrostatic pressure will be used as one form of boundary control, replacing the radial actuators on the small-scale mount. This form of active boundary control using electrostatic pressure is achieved by having electrodes on both sides of the reflector membrane, located circumferentially on a 1-inch annulus. The electrodes have to be parallel to the membrane after inflation to apply uniform pressure control. In order to evaluate the initial shape of electrodes, a 31-inch clear aperture membrane was modeled using membrane elements in Algor and pressure was used to drive it to an f/2 parabolic mirror. **Figure 4** shows the out-of-plane deflections in the outer 1-inch annulus for a range of intrinsic tensile

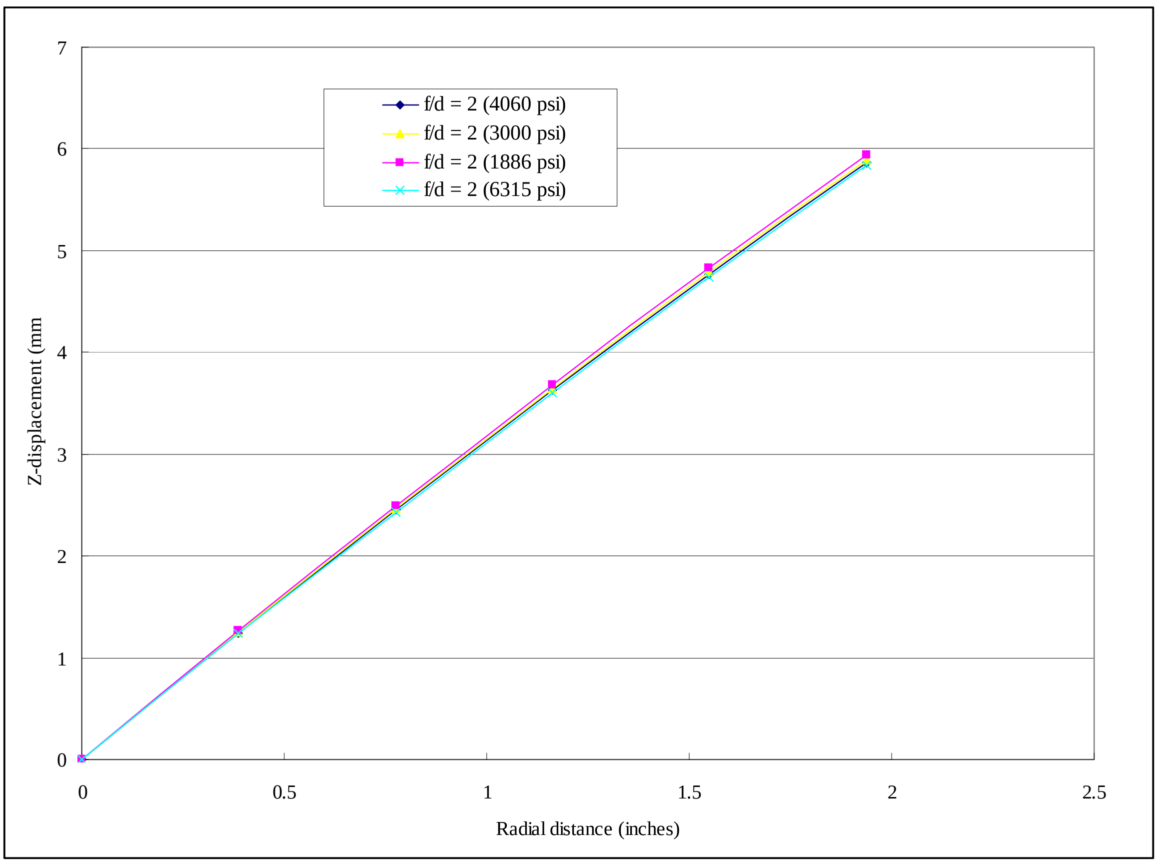


Figure 4. Membrane out-of-plane displacements in a 1.5-inch outer annulus..

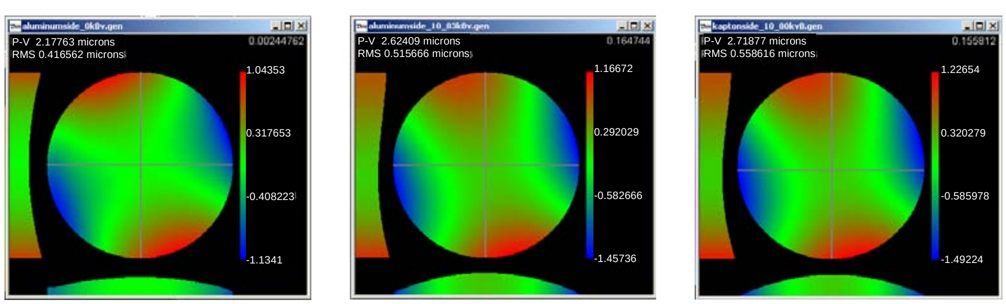
stress in the membrane. Thus, the electrodes will have to be initially inclined with one end at a distance of around 4 mm from the flat membrane such that the electrode's slope equals slope of the membrane after inflation. Provision for changing the distance between the electrodes and membrane are also incorporated into the design.

The system consists of a canopy and mirror film supported by rings that connect and seal together to support a pressure. The membrane mirror is placed against a contact ring that defines the membrane boundary. A reaction ring is used to support the normal actuators as they push against the boundary ring. The boundary ring itself is supported by 18 rods around the diameter and can be lowered further against the membrane mirror simply by reducing the number of precision shims on these support rods. This is available in order to compensate for any reduction of initial stress of the membrane mirror, especially due to the possible use of a lower CTE material.

3. ELECTROSTATIC CONTROL SYSTEM

The PAMM systerm will incorporate linear displacement actuators for out-of-plane boundary warping of the membrane support ring, and radial membrane control will be accomplished by electrostatic pressure actuators located circumferentially around the outer diameter of the membrane just inside of the boundary support ring. The linear displacement actuators were tested on the 0.25-meter small-scale mount and good control authority over astigmatism was demonstrated. Testing was also performed to verify the suitability of high voltage power supplies and the electrostatic control software by applying it to a 14-channel full aperture control on the 0.25-meter mount as reported elsewhere[2].

Since electrostatic control can only pull on the membrane, the 0.75-meter mount was designed to have electrodes placed on both sides of the mirror surface to be able to push and pull on the mirror. Though a total of thirty-six electrodes are needed to achieve the necessary surface accuracy in the mirror, only eighteen power supplies are necessary to provide the high voltage. Two connector boxes with 9 sockets in each was designed, where one end of each socket is soldered to the high voltage lead coming from a power supply and a wire from either an electrode on the inner ring or the outer ring can be plugged into the other end. Gaps between sockets and any open metal parts will be filled with a dielectric to increase the breakdown voltage. Wider spacing distance was allowed were possible without losing any compactness in the design. The electrode rings themselves are being constructed from a nonconductive material using a stereolithography process. The height of the electrode rings is adjusted by simple spring loaded threaded studs at six locations with a fine enough pitch that it does not introduce a pressure leak. The upper electrode will use a simple direct wire connection while the lower electrode is much more complicated since it is situated inside the lenticular system. The lower electrode connection uses a spring tempered metal strip that will contact a connection to the electrode. The electrodes themselves will consist of 127 micron thick aluminum coated Kapton film adhesively attached to a non-conductive support disc. The Kapton layer will be applied so that the Kapton side will be facing the reflector film and the aluminum side facing away to reduce the potential for arcing. The dielectric properties of the film prevent any reduction in force since the electrostatic charge build up is not affected by passing through the Kapton. This was tested by placing one 2-inch square electrode behind an aluminized CP1 film and measuring the shape change for an applied voltage. The same displacement was achieved for both the aluminum facing and Kapton sides facing the membrane under test. **Figure 5** shows the resulting OPD plots for these test cases.



0 V OPD Plot (tilt removed) | 10.83kV Al Facing (tilt removed) | 10.00kV Kapton Facing (tilt removed)

Figure 5. Interferogram results of electrode test.

LabView control software (**Figure 6**) is utilized along with the necessary I/O devices to accommodate the power supplies used. In addition to a proportional master slider to control voltages on all electrodes, checkboxes are provided in order to select channels to form into groups. Channels in each group can be collectively controlled using proportional group sliders. This control system is based on one used previously by SRS on past successful electrostatic systems.

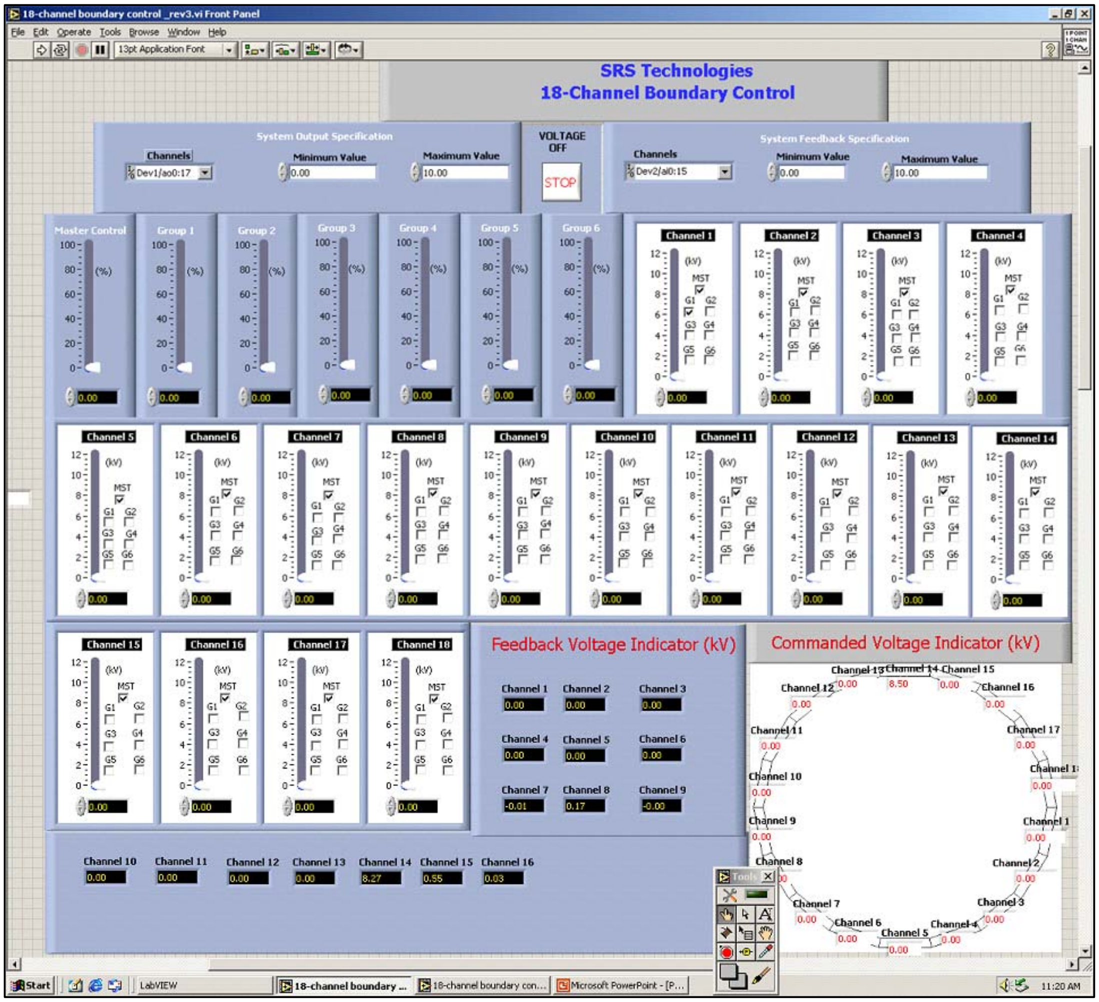


Figure 6. LabView 18-Channel Voltage Control Panel

3. MEMBRANE MOUNT FABRICATION/INITIAL SETUP

Figure 7 shows the described large-scale mount at various assembly stages with no membranes in place. The boundary ring is shown with a close-up of the surface. Since this is the portion of the mount that defines the boundary of the membrane mirror it was critical that this surface have a smooth surface[3]. In order to support the mount system a cradle holder (visible in **Figure 7**) was designed and fabricated to support and lock down the mount. This also has a small actuator that allows the angle about the x-axis to be adjusted to help align the mirror for testing.

The next step was to incorporate membranes into the mounting rings. Four rings were initially made to support membrane mirrors, while one ring was made to support the clear membrane canopy. Excellent results were obtained on the thickness variation for these films. **Figure 8** shows a composite photo of one of an uncoated membrane mirror under monochromatic light revealing the Fizeau fringes (thickness variation). Each transition from light to dark equals

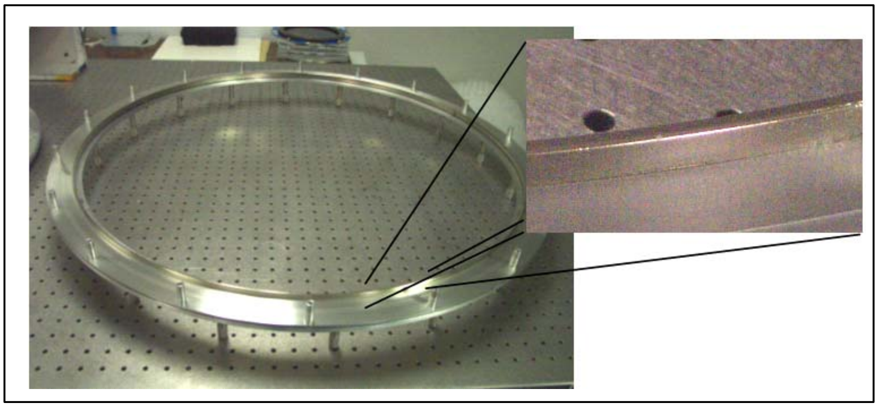


Figure 7. Membrane Boundary Contact Ring

approximately a thickness change of 175nm. For the film shown here there is less than one fringe across the aperture resulting in excellent subwavelength thickness variation. Four membranes were manufactured for the mirror side. Three were sent for required reflective coating application. This included one for a uniform coating and two varied stress coatings. The remaining membrane is being used for internal testing since data can be taken on the uncoated reflectance of CP 1. **Figure 9** shows an inflated membrane system setup at SRS, since the canopy, as well as the mirror in this case, are clear, the surfaces are difficult to see. **Figure 10** shows some initial Ronchi test data from the mirror and the resulting OPD plots with focus removed.

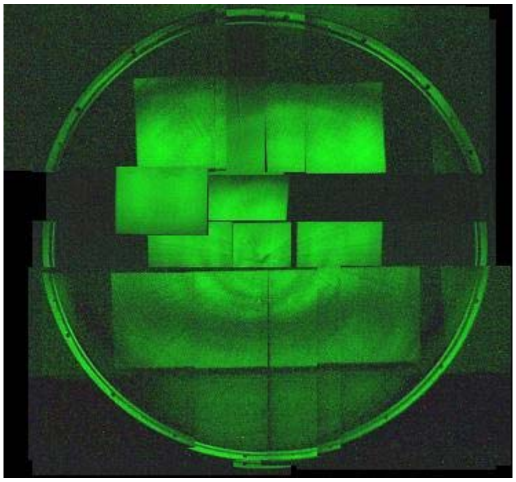


Figure 8. Membrane and corresponding partial Fizeau mapping of membrane demonstrating subwavelength thickness variation

Figure 9. Inflated Lenticular with clear membranes

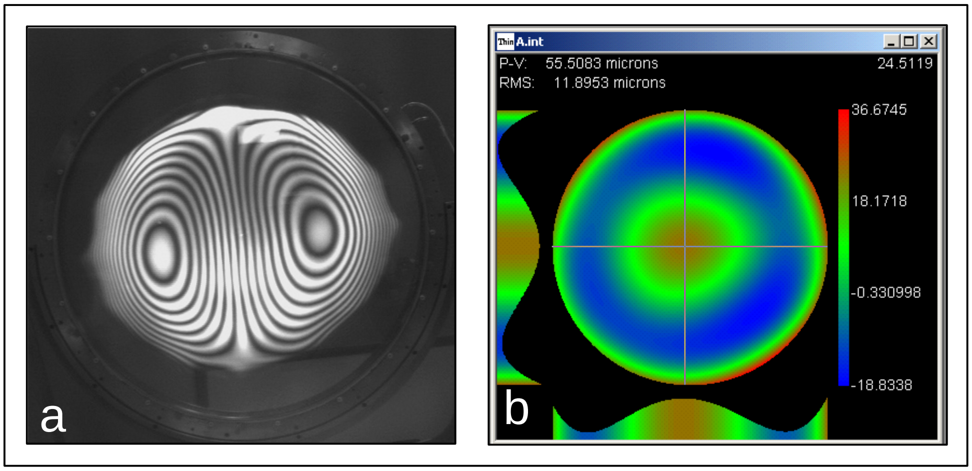


Figure 10. a) Unadjusted, initial Ronchi data taken from membrane with b) OPD plot (focus term removed revealing mainly spherical aberration) of 56cm aperture.

The data shows mainly spherical aberration as well as some astigmatism and coma as the dominate aberrations. Some of the errors from the edge limit the useable aperture, however no tuning has been conducted to the actuators yet to improve this. One reason for this is the fact that the membrane does not have the proper reflective coating applied. This will change the mechanical properties of the membrane by forcing it into a more parabolic shape and thereby reducing the spherical error. This is described in detail elsewhere[4]. Testing of the membrane mirror system as well as preparations for integration with the electrostatic system are currently ongoing,. Test data will be flowed to FEMs and integrated with in-house software for actuator influence function calculations as well as proper actuator positioning to correct the membrane mirror shape.

4. SUMMARY AND CONCLUSIONS

This paper has described activities associated with the development and initial testing of a meter-class membrane mirror system. The integration of active boundary control has been shown through both computer modeling and small-scale testing to be a very effective method for correcting certain types of figure errors typically seen in membrane mirrors while maintaining a low areal density. This, along with the integration of stress coating techniques to the membrane material will help effectively reduce the figure error from a parabola enough to allow available secondary correction techniques to further correct the image.

Testing will continue on this mount to both fully validate finite element models and actuator influence response, as well as demonstrate the feasibility of a lenticular membrane mirror system due to the high quality polymer membranes now available for such optical quality applications.

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